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REPORT NUMBER 541

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Bureau of Medicine and Surgery, Navy Department
Research Work Unit MF022.01.04-9005.04

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SUMMARY PAGE

THE PROBLEM

The underwater scene is distorted visually, due to the refraction of light rays as they pass from water to air. This paper describes two studies of individual responses to distortions of apparent distance and location.

FINDINGS

The apparent distance of objects viewed underwater changes regularly with conditions, from underestimation in clear water at close distances to overestimation in turbid water at far distances. Tests of hand-eye coordination revealed vast differences among subjects in their response to the distorted apparent location of objects; these differences are a function of the length of time subjects have spent underwater.

APPLICATION

The data will be used to predict how individuals working underwater, such as SCUBA divers and operators of small submersibles, will respond to their visual world, what errors they will make, and the means of compensating for such errors.

ADMINISTRATIVE INFORMATION

This investigation vas conducted as a part of Bureau of Medicine and Surgery Research Work Unit MF022.01.04-9005 — Procedures for Improving Vision, Auditory Communications, and Orientation Underwater. The present report is No. 4 on this Work Unit. It was approved for publication on 16 July and designated as Submarine Medical Research Laboratory Report No. 541.

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ABSTRACT

Results are reported on two aspects of underwater vision, apparent distance and hand-eye coordination. The accuracy of distance estimates underwater varies greatly from underestimation at near distances, to overestimation at far distances. Viewing through turbid water rather than clear water greatly increases the tendency toward overestimation. The ability of subjects to perform motor responses adequately using the distorted stimulation underwater has been measured and shown to vary with the time spent in underwater activities.

RESPONSES TO THE UNDERWATER DISTORTIONS OF VISUAL STIMULI

INTRODUCTION

A problem commonly encountered by individuals performing tasks underwater is that both the size and distance of objects are distorted. Under certain conditions objects appear larger and closer than they really are. This distortion occurs, of course, because of the refraction of light rays as they pass from water to air. Theoretically, objects are magnified to 1-$\frac{1}{3}$ their real size and appear at $\frac{3}{4}$ of their real distance. The effects of this physical change in the energy for vision are easy to demonstrate in clear water at close distances. In turbid water or at greater distances, however, the diver's perception cannot be predicted from a simple application of the principles of refraction. Distances may be overestimated rather than underestimated and contours may be so blurred by the diffusion of light by water, that no accurate estimate of size is possible.

An additional problem confronts the diver who attempts to perform tasks under water. Due to the distortions of size and distance, objects are not located in space at the position at which they appear. The diver, particularly the novice, is continually plagued by reaching out for an object only to miss; many trials may be made before successful contact is achieved. Since experienced divers do successfully perform many tasks underwater, presumably some adaptive process occurs. In fact, responses to distorted stimulation, in air, have been extensively investigated; a major result is that human beings are remarkably adaptive, eventually responding appropriately to even the most distorted situations.

This report is an account of underwater experiments on size and distance perception and hand-eye coordination, conducted to find, first, what the diver perceives, and secondly, means of aiding him to respond adequately to his unusual environment.

EXPERIMENT I — PERCEPTION OF DISTANCE

Background

In clear water at close distances, it is a simple matter to observe the effects of refraction. If the face mask is placed vertically at the surface of the water, looking up gives a view entirely through air, and looking down, entirely through the water. With the eyes in the former position, objects are seen in the normal perspective; in the latter position, the same object will appear considerably larger and closer.

Despite this, an experimental investigation of distance perception underwater showed clearly that most subjects overestimated the real distance underwater for distances greater than four feet.[1] The study was conducted in Lake Winnipesaukee, whose water was fairly turbid, overall visibility being limited to about 20 ft. Subjects were naive with respect to underwater experience. Similar overestimations have been reported by Ross for SCUBA divers in the Mediterranean.[2] This apparent conflict between the experience in clear water and the results of field studies led to the present study of distance estimation under varying conditions of water turbidity.

Method

The target, whose distance was to be estimated, was a white metal square, 4″ on each side. Its actual size was unknown to the subject. It was placed in the water at varying distances from 2 to 16 ft. from the subject, who was asked to estimate its distance in terms of a standard target.

The standard was an identical, 4″ square which was placed on an easel in air beside the subject. The distance between the subject and the standard target was two feet. The subject was not informed of the absolute distance but was told that the distance between the target and himself was

one standard unit. He was then to estimate the distance of the target in the water in terms of how many standard units it was from him. This is the same procedure that was used in the earlier investigation.[1]

The study was conducted in an above-ground swimming pool, 20 ft. in diameter. Portholes were cut in the sides through which subjects could view the target in water while they and the standard target remained in air.

The turbidity of the water was controlled by the amount of filtering done. If a standard swimming pool filter was placed in frequent operation, the water could be made extremely clear. On the other hand, cessation of the filtering allowed rapid growth of algae, and turbidities of any desired degree could be obtained. The degree achieved was measured with a *Marine Advisers' Alpha Meter*.

Two conditions were used: "Clear," which covered alpha readings between .2 and .7 (transmissions of .50 to .85 for 1 meter of water) and "turbid," for alpha measures between 1.0 and 1.2 (T of .30 to .38). Under the "clear" condition, the range of visibility extended throughout the entire 20 ft. of water available. Under the "turbid" condition, visibility was restricted to 14 to 16 ft. Twenty different subjects were tested under each condition.

Results

The median estimates of distance, in standard units, are shown for the two conditions in Fig. 1. Estimates for the turbid water condition are greater at all physical distances than are those for clear water. The straight line at 45° is the function for physical equality between estimates and actual distances. Both curves are below this line, showing underestimation, at short distances. At approximately two standard units, (4 ft.), the curves cross over the equality line and reveal increasing overestimation from that point on. The overestimation of the longer distances is sizeable; a target at 8 standard units (16 ft.) is estimated to be at 13 (26 ft.) by subjects viewing it through turbid water.

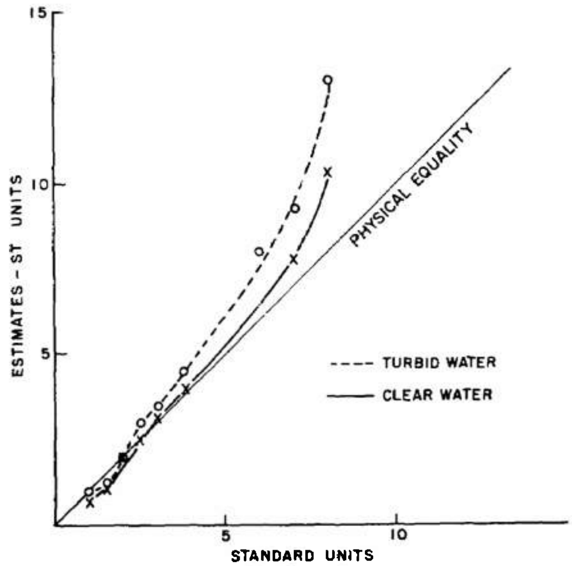

Fig. 1. The effect of water clarity on the perception of distance.

Figure 2 is an enlarged portion of Fig. 1, for short distances and shows the crossover more clearly. Also plotted in the figure is the function for the optical distance of the targets, $3/4$ of the value for air. Only the data for the subjects who were viewing through clear water at two and three feet fall on this line. Even at these very close distances, the subjects looking through turbid water overestimated the distance with respect to the optical image.

The range of the individual estimates is pictured in Fig. 3. The lower limit of the range is similar for the two groups, while the upper limit is larger, without exception, for the group viewing through turbid water. This could indicate that some individuals are less influenced than others by the turbidity in judging distances.

Discussion

These data resolve the apparent conflict between the overestimation of distances reported for field conditions and the underestimation expected from the change in the optical image due to refraction. The latter is effective only under the ideal conditions of clear water and distances within about an arm's length or less. Under all other conditions, overestimation with respect to the optical image occurs. This overestimation

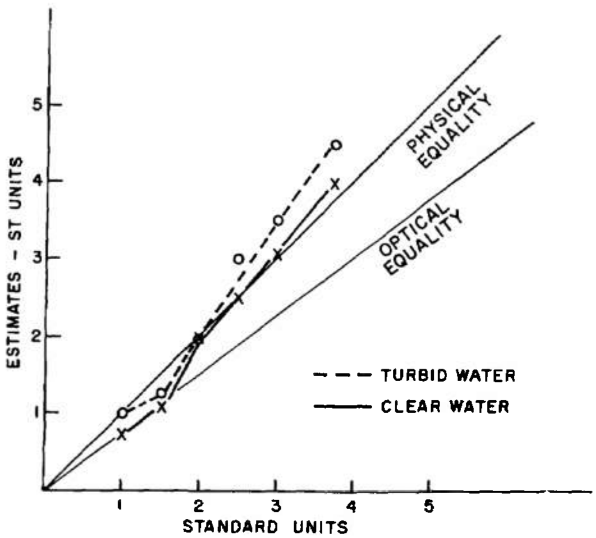

Fig. 2. Distance estimates when the target is close to the subject.

becomes excessive under poor viewing conditions (longer distances or turbid water), exceeding the actual physical distances by large amounts.

There are, of course, large individual differences in the ability to estimate distances underwater. Previous results[1] suggested that experienced divers may overestimate less than naive subjects. This possibility and the question of whether or not divers might be less distracted by turbidity will be investigated in future research.

EXPERIMENT II — HAND-EYE COORDINATION

Background

The remarkable ability of human subjects to adapt, in time, to all kinds of distortions of visual input and eventually to respond appropriately to the new stimulation has been known since the demonstrations performed by Stratton.[3] In one case, Stratton wore inverting lenses in front of his eyes for eight days and reported that after this length of time he was able to respond appropriately to the upside down images and even to see things as "normal." More dramatic demonstrations are to be found in the works of Ivo Kohler,[4, 5] whose subjects eventually were able to ski, fence, and ride a motorcycle while wearing inverting lenses.

Considerable interest in the process has been displayed in recent years and dozens of experiments performed to obtain information on the factors influential in determining how much adaptation will occur and on its theoretical explanation.[6-11] The major difference between the current studies and the work of Stratton and Kohler is the increased quantification found in the newer work. While most of these studies deal with the adjustments in visually guided behavior, similar changes can be found in the other senses.

In the visual system, the distortion is usually introduced by the use of prisms or lenses which transform the optical image so that it appears to be a different size, shape, distance, or in a different position from what it actually is. The subject, when asked to touch or pick up an object, will misreach at first. The misreaching is gradually

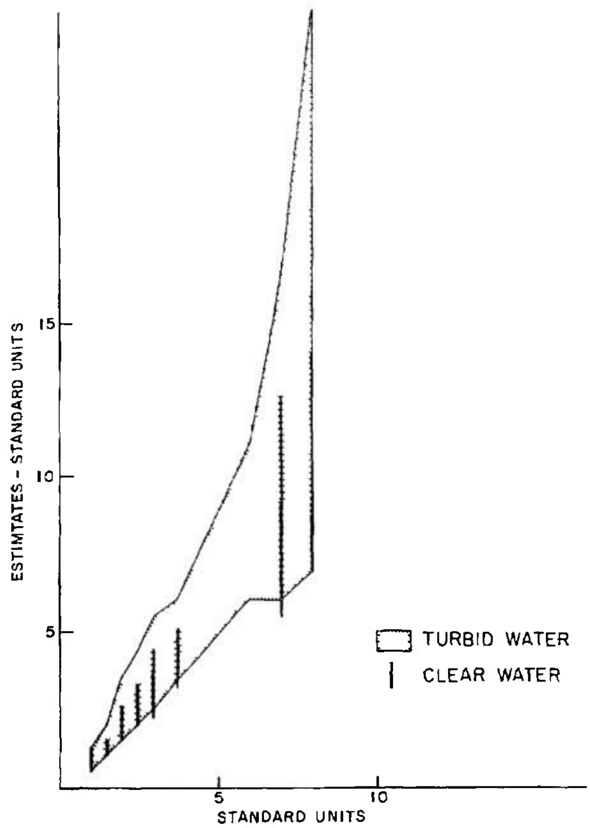

Fig. 3. Ranges of distance estimates for subjects viewing the target through clear and through turbid water.

reduced over time until the subject is able to perform motor responses completely appropriate to the distorted visual display. The process of adjusting to the new stimulus conditions, called adaptation, is further attested to by the fact that, after the distortion is removed, the subject will misreach in the opposite direction.

The experimental paradigm in the majority of the studies in adaptation involves testing some perceptual-motor response prior to and following a designated time period of exposure to the distortion. Data are generally not collected in the adaptation period itself, but rather the size of the after-effect is measured and compared with data from the same task in the pre-exposure trials.[8]

The refraction of light energy as it passes from water to air distorts the optical image in the same way as a magnifying lens. The task of the diver, therefore, in adapting to this distorted visual scene, is the same as that of subjects in typical adaptation experiments — they must learn a new system of hand-eye coordinations compatible with the new stimulation. Much of the information available from the adaptation studies in air therefore is directly applicable to this problem. For example, it has been shown that the most efficient means of adjusting to the distortion is for the subject to actively move around in the environment; simply viewing the scene passively results in little or no adaptation.[6, 7]

On the other hand, certain questions important in the diving situation are not answered from the studies which test primarily the after-effects of the distortion. For the diver, responses **during** the adaptation period are of much greater importance than the size of the after-effect (that is, what happens when he returns to air). One wishes to know how long it takes to adapt to the underwater distortions; whether the diver must readapt each time he enters the water, and, if so, is the time required on the subsequent exposures shorter; whether there are individual differences in ability; and whether there are techniques which might be applied to speed the adjustment process.

This investigation is an attempt to answer some of these questions by measuring hand-eye coordination or visually guided behavior of various subjects before and during exposure to the underwater conditions. The work is still continuing.

Method

Reaching behavior was measured on a specially constructed table, two feet square, with a flat white top on which there were four designated positions marked by crosses. The subject's task was to mark on the underside of the table each of the positions which he could see on top. The subject thus was not able to see his hand in relation to the stimuli during testing; this, of course, would enable him to compensate for his error.

One measurement session consisted of five marks for each of the four positions and took about three minutes. The order of positions to be marked was randomized and given to the S verbally. He was instructed to return his hand to his side after each mark.

Each subject was tested in air prior to the water exposure to determine his base line ability in this task. Measures were made on the same apparatus, immediately upon entering the water, after 15 minutes, and after 30 minutes exposure to the underwater environment. A second trial in air was given all subjects approximately one month after the end of the water trials. Subjects wore face masks for the testing, both in air and in water, to eliminate this as a source of difference.

Underwater Exposure

All underwater work took place in a swimming pool 20 ft. in diameter. The water was clear and its depth was four feet. For the reaching response measures, the table was placed in the pool.

Subjects were provided with a snorkel and face mask and remained underwater for the 30-minute exposure period. They were told to be as physically active as possible and were provided with objects for which they

could dive; they were told to pick up the objects and arrange them in patterns. They were also given a crossword puzzle to solve on an underwater slate and a modified game of checkers to play on an underwater board. These items were selected in order to give the subjects as much and as varied experience as possible in reaching, grasping, and coordinating their visual and motor behavior. The entire underwater procedure was repeated in a second session, approximately one week later.

Subjects

Eight individuals served as subjects. They were chosen to sample different extremes of underwater experience. Two subjects were qualified Navy divers with 100 hours or more experience underwater. Two were completely inexperienced, never having used the snorkel and face mask previously. The other four could be classified as novice divers, with fairly extensive snorkel-face mask exposure and some SCUBA experience, but the latter totalled less than ten hours underwater.

An additional six subjects were given the same test four times, all in air, as a control.

Data Analysis

A scale drawing of the table top with the actual positions marked is shown in Fig. 4. Also indicated are the placement of the four positions as they appear to the subject due to the refraction of the water. If the subject marked the positions in accord with their physical location, the marks should appear under the crosses; if they marked according to visual appearance, they would lie under the arrowheads.

The positions of the subject's marks are measured, in inches, from two reference points. One, the near edge of the table, represents the 3-dimensional plane or the subject's perception of the distance between himself and the object. The other, the side edge of the table, represents the frontal plane or the subject's perception of the magnification of objects.

In each case the subject's response in air is used as a norm against which the data

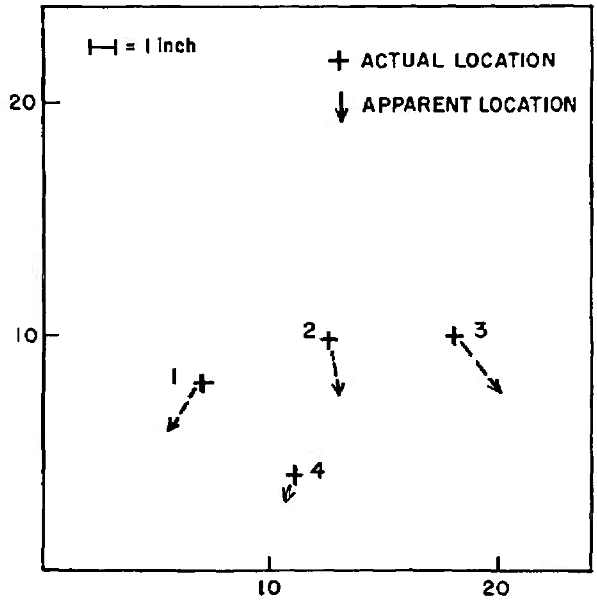

Fig. 4. Schematic design of the targets used to measure hand-eye coordination, showing their physical location, and their apparent location in water.

obtained in the water are evaluated. The measures of the positions obtained in water are subtracted from comparable measures for the air control. If the result is zero, the subject has responded exactly the same in water as in air (that is, he has responded according to the physical position rather than the appearance.)

For the 3-dimension measure, a positive value means the S underestimated the distance, and a negative value, that he overestimated it. The average change in the optical image due to refraction is two inches; thus, a value of +2.0 inches means that the subject responded according to the visual appearance of the position only.

For the measures in the frontal plane, very little distortion is expected for positions #2 and #4 (1/3 inch or less) since they lie so close to the mid-line of the table. The data for positions #2 and #4 have, therefore, been kept separate from that of positions #1 and #3. For the latter two positions, distortions of almost two inches occur. Positive values, in all cases, mean the markings in water were closer to the edges of the table than they were in air; this is the direction of the visual appearance. Negative values mean

the water marks were closer to the mid-line than the marks in air, and zero, again, means perfect physical conformity between air and water.

Results

The data for the eight individual subjects are given in the Appendix. There is considerable variability and individual differences are sizeable. Average data will be presented in this section in order that meaningful trends can be sought apart from individual variability. The data have been averaged for groups of subjects according to their history of underwater experience, since this was the most obvious source of individual differences.

Figure 5 indicates the amount of change in the 3-D plane from the air control, in inches, as a function of the time spent in the water for the three groups of subjects. For the subjects with no underwater experience, there was considerable underestimation of the distance in the positioning of their marks. The amount of this underestimation did not change much during the entire session. During the second session, these individuals showed a marked reduction in the amount of coordination error, but continued to show a sizeable discrepancy at the end of the 30-minute session.

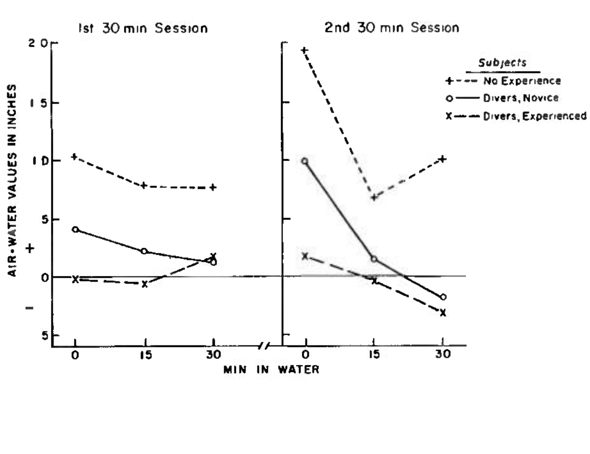

Fig. 5. Changes in apparent positions of targets in 3-dimension during two thirty-minute sessions underwater.

The data for the novice divers show the expected underestimation of distance when they first enter the water but a fairly rapid adaptation to the zero baseline. There is no evidence of retention of this learning, however, the underestimation at the beginning of the second session was larger than at the beginning of the first. Complete adaptation, however, occurred within 15 minutes or less.

The data for experienced divers are completely different; there is never any underestimation, the divers showing excellent hand-eye coordination to the distorted stimulation throughout the testing periods.

Figure 6 shows the comparable analysis for the adaptation in the frontal plane. The data have been divided into two halves: those for the positions in the center of the board, at the top of the figure, and those for the positions near the sides of the board,

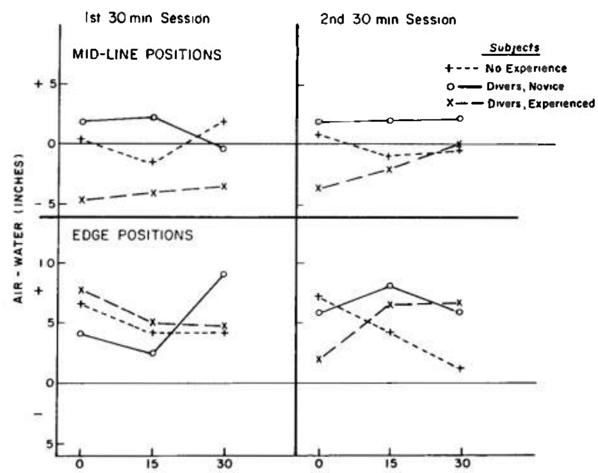

Fig. 6. Changes in apparent positions of targets in frontal plane during two 30-minute sessions underwater.

at the bottom of Fig. 6. In the first case, no adaptation is expected, since the light path from the position mark to the diver is essentially parallel and undistorted. The data vary randomly around the zero baseline and show no evidence of change over time.

Considerably more error is found in the data for the position marks at the sides of the board. All subjects perceived the marks

as farther out to their right or left than they actually were, in accord with the magnified visual stimulation. On the other hand, there was little evidence of adaptation for most of the subjects. Even the divers misreached in this dimension and showed no improvement over time.

The data for the three groups of subjects are summarized in Figs. 7 and 8 which show the average results for the two underwater sessions. For the 3-dimensional plane, Fig. 7, there are striking differences among groups which range from some, but inadequate, adaptation over time for the inexperienced subjects to complete adaptation for the experienced divers. In the frontal plane, Fig. 8, the functions over time are almost horizontal, at a level (either positive, revealing distortion by magnification, or zero, showing no distortion) determined by the position in the field.

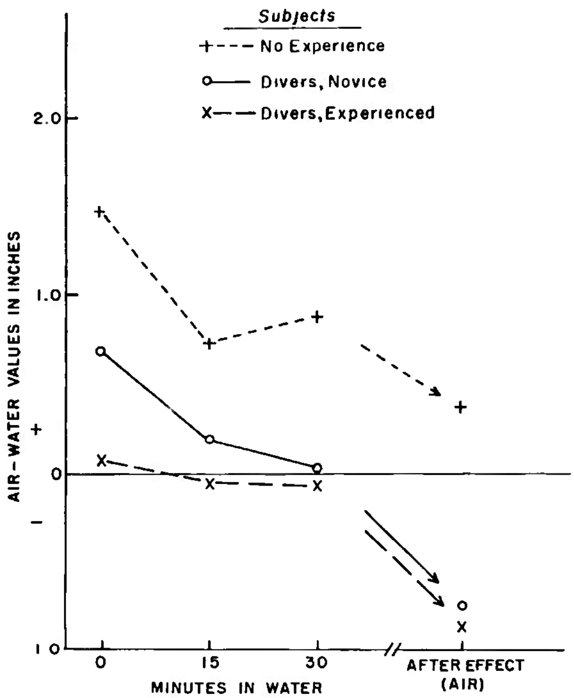

Fig. 7. **Adaptation in 3-dimension averaged over two underwater sessions and the after-effect measured in air.**

The data for the second trial in air are also pictured in these figures. In the three-dimensional plane, there is a decided shift downward, toward overestimation, in the data of all subjects. This result is in complete accord with the typical results of adaptation experiments performed in air. After adaptation to distorted stimulation has been achieved, subjects overcompensate in the opposite direction upon removal of the distortion.[8]

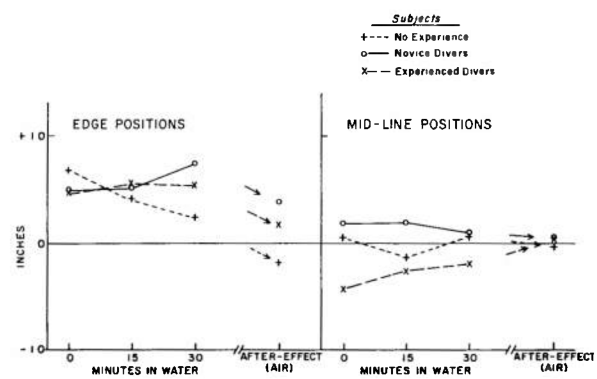

Fig. 8. **Adaptation in frontal plane averaged over two underwater sessions and the after-effect measured in air.**

In the frontal plane, the data for the second air control simply tend toward zero, or no difference between the first and second air sessions. This, too, is the expected result since there is no evidence of adaptation having been achieved in this dimension.

The results of the air control subjects are shown in Fig. 9. This figure presents the data portrayed on the top of the apparatus. The mean positions for the six subjects are indicated, surrounded by circles showing the size of one standard deviation around the means. The data for the first two sessions are compared with that of the last two sessions; there is no evidence of any change over time.

Discussion

The major result of this study is that individuals with different degrees of proficiency in the underwater environment respond in vastly different ways to the underwater distortion of visual stimuli. The fact that the subjects with no experience showed such relatively little adaptation undoubtedly stems

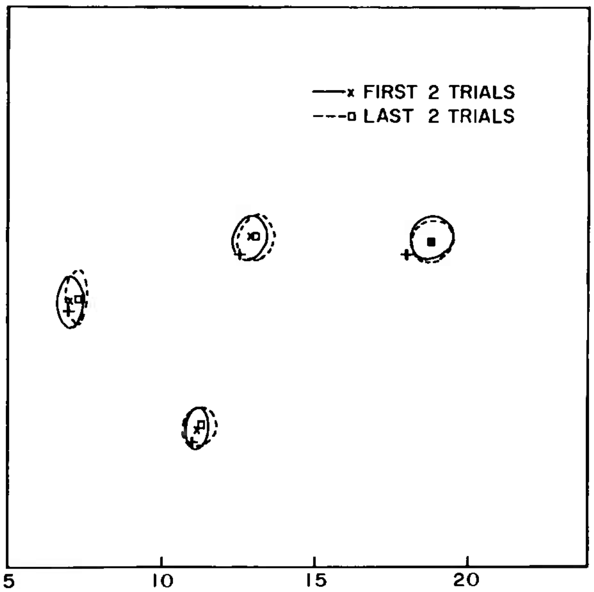

Fig. 9. The means and standard deviations for control subjects in air on the hand-eye coordination test.

from a complete occupation with the process of breathing. This must become routine or automatic before they can attend to the visual world underwater and learn from it. Anectodal material from beginning divers, who suddenly "see" objects that had always been present physically, is a manifestation of the same phenomenon.

The results of the novice divers are in complete accord with the vast number of distorted studies performed in air. Adaptation is rapid and complete. After 15 to 30 minutes of active manipulation of objects and participation in activities in the distorting situation, individuals can perform perfectly adequately in the new situation. There is, however, no evidence in these data of any carry-over from one session to the next.

The divers, on the other hand, show complete adaptation immediately upon entering the water; not even a few minutes are required to adjust to the distortion in stimulation. This leaves unanswered the question as to how much experience is required before complete adaptation is retained from one underwater experience to the next. One of the novice divers was tested in two additional, half-hour sessions underwater in an attempt to gain some data on this question. By the fourth session, the data were similar to those of the experienced divers. On the other hand, all competency in hand-eye coordination had been lost by the next underwater experience several months later. Thus, the question of the amount of experience or practice required to retain the visual-motor adjustment must await further research.

Another interesting question concerns the differences in adaptive behavior found in the two spatial planes, the 3-dimensional and the frontal. Adaptation is complete only in the 3-dimensional plane and almost nonexistent in the frontal. The difference relates to a distinction in the common responses to distortions in these planes. The three-dimensional plane is the one in which the most active degree of visual-motor coordinated behavior occurs, as the individual reaches for, grasps, and picks up objects. The distortion in the frontal plane, however, may be completely visual. Objects natural to the underwater world appear magnified, but the diver will be unaware of the discrepancy unless he attempts to manipulate them. The question as to whether the visual size of objects shrinks to its physical size as the diver adapts to the distortion is as yet unanswered. This could be one outcome of the adaptation process. On the other hand, at least one theory predicts no change in the visual aspect of the situation.[12] The theory, based on evidence that vision always dominates over touch, states that the adjustments occurring in adaptation to distorted stimuli all take place in the tactual or kinesthetic sense, for example, in the "felt position" of the arm. Future studies are being designed to answer this question.

The pronounced after-effect found in the second measurements performed in air is interesting from both the practical and theoretical points of view. Although the run was postponed for about a month, to eliminate after-effects, that period of time obviously was not sufficient. Normally, in studies conducted in air, after-effects dissipate quickly, no measurable amount being

found after 15 minutes. This obviously constitutes a major difference between the air and water studies.

Some investigators of adaptation to distorted stimulation view the phenomenon as simply a special case of motor learning.[9] This thesis has been extended by Taylor,[13] whose explanation is that adaptation is essentially conditioning of motor responses to a vast array of new types of stimulation. In addition to the visual inputs, these include sub-systems of tactual and kinesthetic stimuli, specific to the experimental situation, such as the pressure of prism-holders on the nose, the narrowing of the visual field, etc.

The underwater environment includes many such specific sub-systems, such as the feel of the face mask, sensations of being wet and cold, kinesthetic stimuli from pressure on respiratory system, etc. Most of these stimuli are specific to the diving situation and thus are not available for reconditioning to responses in air. This lack of availability for conditioning to new stimuli might then be the explanation of the prolonged aftereffect.

The advantage to divers is that the adaptation, or the learning of motor responses in response to stimuli provided by the underwater world would, once achieved, not be expected to disappear quickly, and might even last for extensive time periods. This possibility will be tested in future work.

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APPENDIX

INDIVIDUAL MEASURES ON HAND-EYE COORDINATION TASK

All values indicate the average position of the subjects' 5 marks in inches.
S refers to measurement from the edge of the board closest to the target.
B refers to measurement from the bottom of the board.

	Target Positions							
	1		2		3		4	
Condition	S	B	S	B	S	B	S	B
Subject 1 - Experienced Diver								
AIR								
Trial 1	6.58	7.85	11.58	10.30	6.15	10.32	11.12	4.00
Trial 2	6.38	8.58	12.00	10.78	5.95	10.92	10.58	5.30
WATER								
Session 1								
(0 min)	4.52	8.38	12.38	10.68	4.92	10.62	10.75	3.70
(15 min)	4.65	7.95	12.98	10.52	5.92	10.65	10.28	4.20
(30 min)	5.05	8.12	12.55	10.25	5.80	10.25	10.50	3.92
Session 2								
(0 min)	6.12	7.22	12.00	9.75	5.32	9.90	11.22	3.78
(15 min)	5.00	7.98	12.62	10.08	5.52	10.42	10.62	4.25
(30 min)	5.45	8.52	12.31	10.78	5.02	10.95	10.58	4.68
Subject 2 - Experienced Diver								
AIR								
Trial 1	6.88	8.90	10.56	11.16	5.08	11.29	11.56	4.62
Trial 2	5.50	9.82	11.65	12.12	6.18	12.08	10.38	5.62
WATER								
Session 1								
(0 min)	4.85	8.83	12.68	10.62	7.28	10.97	10.89	4.82
(15 min)	5.00	8.61	12.62	10.76	7.11	11.38	10.56	4.90
(30 min)	5.65	8.36	12.40	10.59	6.33	10.88	10.84	4.69
Session 2								
(0 min)	5.85	8.90	12.58	11.50	6.64	11.48	10.52	4.58
(15 min)	5.69	8.50	11.85	11.45	5.92	11.52	10.20	4.51
(30 min)	6.00	8.73	10.95	11.39	5.70	11.22	10.97	4.81

	Target Positions							
	1		2		3		4	
Condition	S	B	S	B	S	B	S	B
Subject 3 - Novice Diver								
AIR								
Trial 1	7.01	10.04	10.46	12.14	3.79	11.94	11.12	5.45
Trial 2	6.50	11.52	11.10	13.30	4.21	13.12	10.38	6.31
WATER								
Session 1								
(0 min)	5.38	9.35	11.38	12.08	4.85	11.90	10.02	5.00
(15 min)	5.98	11.50	10.92	13.68	4.85	12.90	10.12	5.90
(30 min)	5.15	10.38	12.02	13.20	5.05	12.82	9.62	4.42
Session 2								
(0 min)	5.26	9.39	10.94	12.40	3.89	12.25	10.28	3.62
(15 min)	4.30	9.78	12.38	13.12	4.80	13.22	8.72	4.56
(30 min)	4.39	10.41	12.26	13.35	5.42	13.35	8.48	4.71
Subject 4 - Novice Diver								
AIR								
Trial 1	5.52	9.78	12.20	11.85	6.48	11.40	10.38	5.20
Trial 2	6.05	11.05	11.48	12.78	5.55	12.38	11.30	6.62
WATER								
Session 1								
(0 min)	5.95	8.10	10.78	10.38	5.10	9.92	10.60	3.98
(15 min)	6.68	8.78	10.68	10.80	4.25	10.42	10.98	3.98
(30 min)	6.60	9.78	10.35	11.90	3.62	11.48	11.90	4.08
Session 2								
(0 min)	6.98	7.30	10.42	9.40	4.60	9.00	11.15	2.90
(15 min)	6.62	9.40	9.90	11.70	3.40	10.98	12.05	3.88
(30 min)	6.35	10.38	10.32	12.05	3.82	11.80	11.78	3.95

Condition	1 S	1 B	2 S	2 B	3 S	3 B	4 S	4 B
	Target Positions							
Subject 5 - Novice Diver								
AIR								
Trial 1	6.75	10.15	11.02	12.55	4.48	12.50	10.80	5.75
Trial 2	7.19	11.35	10.41	13.28	3.31	13.40	10.96	6.80
WATER								
Session 1								
(0 min)	6.15	9.45	11.89	11.78	4.78	12.09	10.75	4.22
(15 min)	6.90	9.58	11.00	11.78	4.42	11.70	10.88	5.12
(30 min)	6.80	10.18	10.60	12.28	3.58	12.05	11.32	5.22
Session 2								
(0 min)	6.80	9.24	10.09	12.08	3.45	11.45	11.19	4.16
(15 min)	5.74	10.24	11.12	13.00	4.20	12.66	10.28	5.26
(30 min)	6.95	10.45	10.32	12.88	4.04	12.78	10.88	5.78
Subject 6 - Novice Diver								
AIR								
Trial 1	7.58	9.10	11.41	11.00	5.85	10.59	10.98	4.92
Trial 2	7.45	8.38	11.65	10.48	6.10	10.58	10.88	4.78
WATER								
Session 1								
(0 min)	6.72	10.18	11.52	12.11	5.11	12.38	9.95	4.82
(15 min)	5.94	8.61	12.26	10.82	6.42	11.40	9.98	3.98
(30 min)	5.62	8.36	12.78	11.00	5.88	11.29	9.94	3.74
Session 2								
(0 min)	5.70	8.62	12.48	11.35	6.08	11.68	10.32	3.85
(15 min)	5.35	8.40	12.40	10.90	6.60	11.35	10.08	3.68
(30 min)	5.55	8.60	12.70	11.28	6.29	11.54	9.81	3.78

Condition	1 S	1 B	2 S	2 B	3 S	3 B	4 S	4 B
	Target Positions							
Subject 7 - No underwater experience								
AIR								
Trial 1	7.75	9.02	10.65	10.90	4.98	10.50	11.38	5.10
Trial 2	7.88	8.38	10.64	10.45	4.86	10.20	11.55	4.74
WATER								
Session 1								
(0 min)	7.40	8.32	10.38	10.62	3.25	10.12	11.42	5.15
(15 min)	7.05	8.98	10.20	11.30	3.95	10.58	11.02	3.90
(30 min)	6.75	9.12	10.90	11.18	3.97	10.59	11.10	4.48
Session 2								
(0 min)	6.58	7.82	10.45	10.22	4.00	9.62	11.12	4.30
(15 min)	6.05	7.55	11.38	9.95	5.00	9.05	10.60	3.60
(30 min)	6.52	7.58	11.12	9.75	4.68	9.62	10.82	3.40
Subject 8 - No underwater experience								
AIR								
Trial 1	7.46	9.41	10.44	12.08	3.48	11.82	11.32	5.30
Trial 2	7.50	9.62	10.70	11.65	4.00	11.31	11.00	5.18
WATER								
Session 1								
(0 min)	6.64	7.96	11.01	10.46	3.74	10.36	10.81	2.90
(15 min)	6.72	8.02	10.92	10.56	4.26	10.95	11.26	3.62
(30 min)	6.64	7.68	11.33	10.23	4.61	10.52	11.24	4.24
Session 2								
(0 min)	7.19	6.69	9.88	8.91	3.08	8.72	12.02	2.28
(15 min)	6.02	9.38	11.52	12.15	4.90	12.18	10.70	4.78
(30 min)	6.48	8.88	11.50	11.56	5.55	11.25	10.55	4.05

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13 ABSTRACT

This report is an account of underwater experiments on size and distance perception and hand-eye coordination, conducted to find, first, what the diver perceives, and secondly, means of aiding him to respond adequately to his unusual environment.

Results are reported on two aspects of underwater vision, apparent distance and hand-eye coordination. The accuracy of distance estimates underwater varies greatly from underestimation at near distances, to overestimation at far distances. Viewing through turbid water rather than clear water greatly increases the tendency toward overestimation. The ability of subjects to perform motor responses adequately, using the distorted stimulation underwater, has been measured and shown to vary with the time spent in underwater activities.

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	ROLE	WT	ROLE	WT	ROLE	WT
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Distortion of distance underwater						
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